

THERMAL INSULATION PROPERTIES OF EXPANDED POLYSTYRENE AS CONSTRUCTION AND INSULATING MATERIALS

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ABSTRACT

Laboratory thermal conductivity testing of insulating materials provides useful information about the nature of such materials; the resulting data may be characterizing in-service performance. In construction installations, insulation continues to function under a variety of temperature, humidity and total assembly conditions. The total insulation-building construction assembly is important to control and predict the long-term characterization of a structure according to taken laboratory test results. In the process of assessing design values for thermal conductivity of insulating materials, knowledge of density, thermal conductivity, material class, mechanical properties of the insulation performance is very important. In this study, experimental tests are applied for the expanded polystyrene as insulating and construction materials which are homogeneous or close to homogenous, porous, grainy or multilayer. The plate method has been used for experimental studies according to standards. Using this apparatus the thermal conductivity of extruded polystyrene are determined. In this apparatus, which can be used for the materials whose thermal conductivity is between 0,036 and 0,046 W/mk, densities of expanded polystyrene are between 10 and 30 kg/m³. The results and experimental methods are discussed according to well known standards. Expanded polystyrene is affected by changes in the composition of the materials in the cells.

KEY WORDS: plate method, polystyrene hard foam boards, thermal conductivity coefficient.

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1. INTRODUCTION

World's fossil fuel reserves are decreasing day by day. Most of the energy is spent for heating purposes. Despite of the fact that fossil fuel resources are decreasing, world has still got enough resource in order to use for heat insulation purposes or heat insulating materials. At the phase of construction, by appraising these resources, heat losses can be decreased; structure health and comfort can be gained. Also by spending less energy, individual and country economy will gain.

Not insulated exterior walls are the most important zones for heat losses. In order to be insulated economically, it will be more beneficial to use main mass of exterior walls. By insulating exterior wall, 70% of total heat loss can be prevented [1, 2]. Insulation must be economic and must prevent an increase in the building dead load. Analyses on Polystyrene materials show that, for the same thermal conductivity resistance, it is the most economic and most light one in weight in Polyethylene materials. [3]. Building products produced from Polystyrene are appropriate materials for building types and wall systems. [4]. For this reason, polystyrene material (See Fig. 2) that has a 15 % usage ratio in plastics that is a petrochemical product (See Fig. 1) is chosen. This is because, polystyrene has a high insulation and low weight resulting a not much increase in building dead loads is chosen. This material has a wide usage area in buildings.

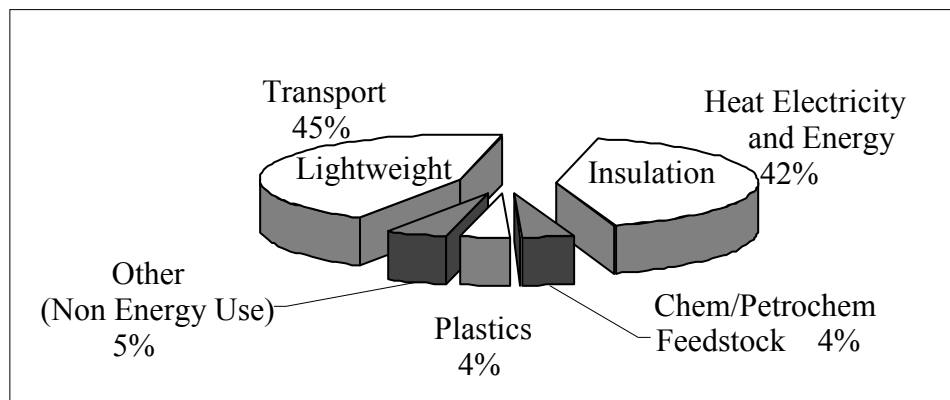


Fig. 1. Plastics are based on oil [5].

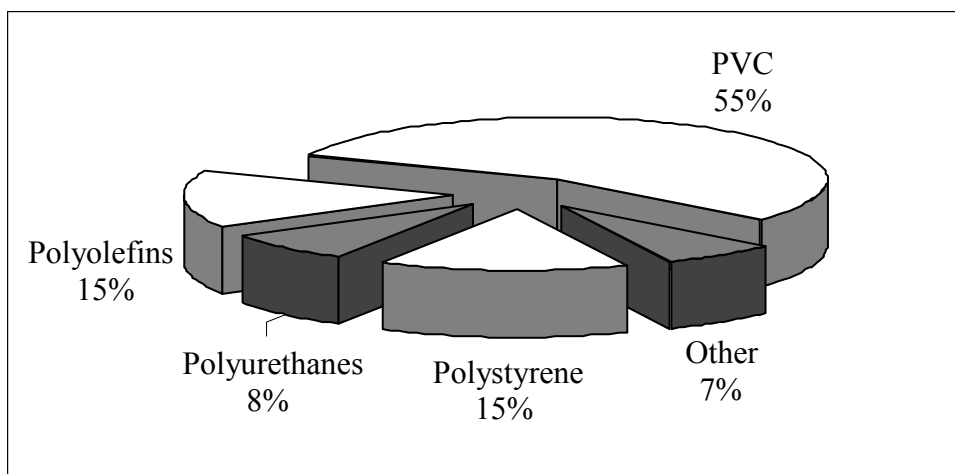


Fig. 2. Plastics in building and construction [5].

2. HARD POLYSTYRENE FOAM

Hard Polystyrene Foam Boards are insulation materials produced by molding sprayed styrene resin polymerization under pressure (Extruded Polystyrene – XPS) or by pressing polystyrene grains into molds expanded under steam or in hot water with the help of steam again (Expanded Polystyrene – XPS) (See Fig. 3) [6, 7].

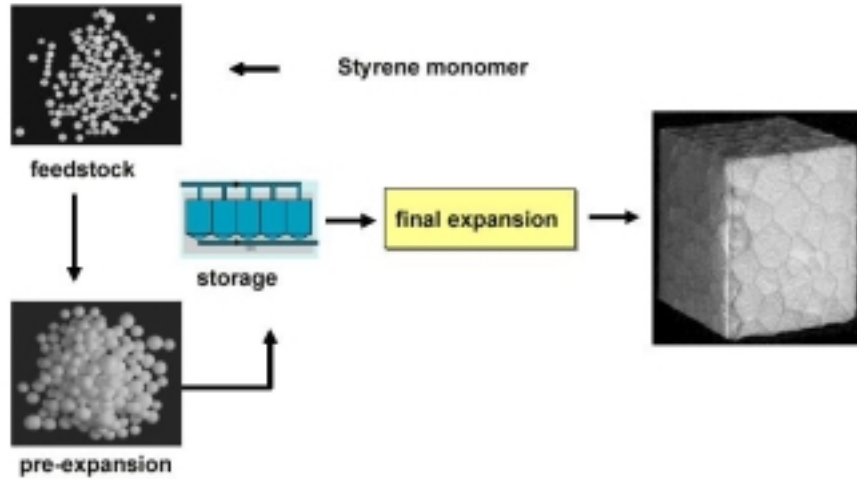


Fig. 3. Expanded polystyrene (EPS) process [5].

Motionless air has a very low thermal conductivity rate. Foam Materials made of Polystyrene contains nearly 98% air. The solid phase (foam skeleton) that conducts the heat takes 2% of the total volume. In addition to this, the polystyrene material that transfers the heat is a very insulating material. Because of the fact that Polystyrene Foam Material takes form from very little (1m³ EPS Polystyrene Foam material consists of 3-6 billion cells) closed cells: 0.01-0.1 mm in diameter (See Fig. 4), the conduction rate of heat by air movement decreases with more little cell volumes thus from the side of insulation technique, it is good insulating material. Heat rays can be prevented best by more number of laminates. First of all; the property that takes attention is the unit weight of polystyrene foam material is less. The weight of foam material that is obtained by kinds of methods with pre swelling is varying from 10-100 kg/m³. Also thermal conductivity value varies according to production density. Generally the standard foam material that is used at construction sites has a density of 10 - 30 kg/m³ [3, 8].

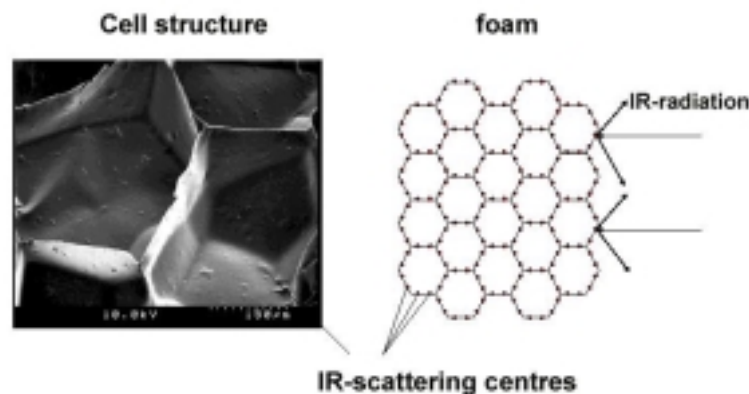


Fig. 4. Reduced heat conductivity – microstructure [5].

The most general usage area of polystyrene foam for heat insulation purposes are at Constructions; wall, ceiling, roof and prefabricated elements. Other areas of usage are for noise insulation, decorative ceiling boards and placing holes in concrete molds. The polystyrene that is pre swelled is used also at production of light concrete and light brick. In cooling technology, Polystyrene Foam material is being used at insulation of cooled warehouses, railway cars, ships, trucks and also at insulation of pipes. Durability of this material exposed to heat varies according to period and degree centigrade under exposure. Despite of the fact that it is durable against heat up to 100 °C for a short period, it is durable and can be used up to 75-85 °C according to its density for a long period [9].

Considering unit weight which is very low when compared with other materials, it is seen that product of polystyrene foam material's compressive strength has an important higher value [3]. The strength of EPS under pressure and resistance to deformation in shape under heat exposure are increasing parallel to increase in unit weight (See Fig. 5). However, water suction capacity is changing according to unit weight and production quality (See Fig. 6). General properties belong to EPS are given in Table 1.

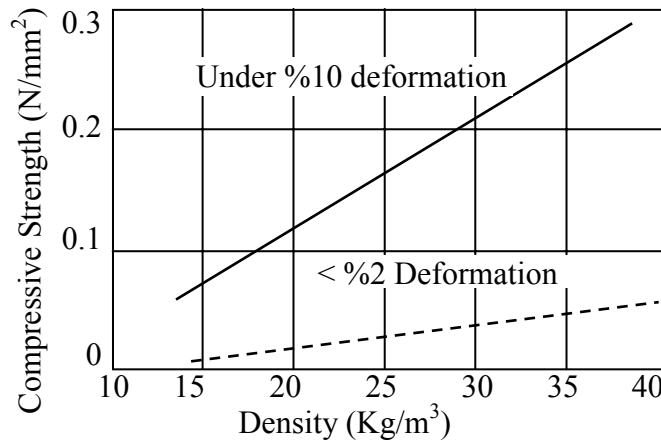


Fig. 5. Compressive strength of EPS according to density & deformation [10].

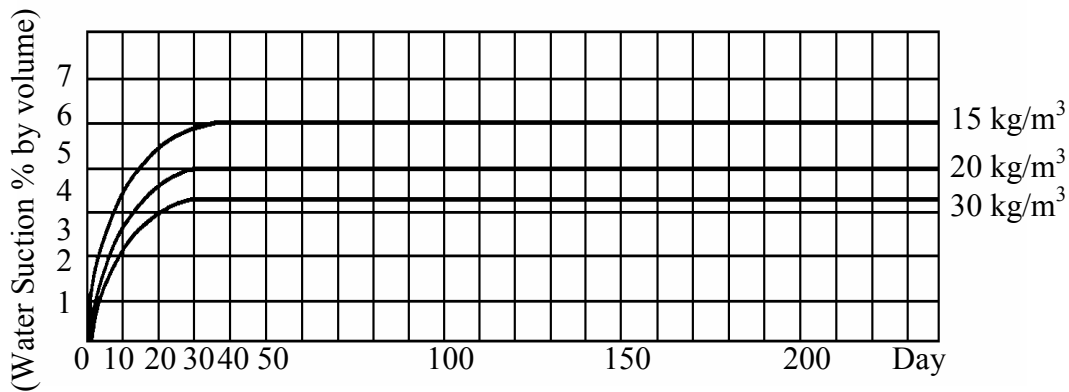


Fig. 6. EPS of water absorption [10].

Table 1. Technical Values of EPS [8].

Properties and Related Standard	Values of EPS		
Minimum density (kg/m^3) (DIN 53420)	15	20	28
Building Material Classification (DIN 4102)	B1 Hardly flammable		
Heat Conductivity Lab. Value (W/mK) (DIN 52612)	0.036-0.038	0.034-0.036	0.031-0.033
Measurement value (W/mK) (DIN 52612)	0.040	0.034	0.033
Compression Strength at 10 % deformation (DIN 53421)	0.07-0.012	0.12-0.16	0.18-0.26
Compression Strength at deformation less than 2 % (DIN 53421)	0.012-0.025	0.002-0.035	0.036-0.0362
Shear strength (N/mm^2) (DIN 53427)	0.09-0.12	0.12-0.15	0.19-0.22
Bending Resistance (N/mm^2) (DIN 53423)	0.16-0.21	0.25-0.30	0.42-0.5
Tensile Strength (N/mm^2) (DIN 53430)	0.15-0.23	0.25-0.32	0.37-0.52
E – modulus (N/mm^2)	0.16-1.25	1.0-1.75	1.8-3.1
Form Strength according to temperature for a short period ($^{\circ}\text{C}$) (DIN 53424)	100	100	100
For a long period 5000 N/mm^2 ($^{\circ}\text{C}$) (DIN 53424)	80-85	80-85	80-85
For a long period 20000 N/mm^2 ($^{\circ}\text{C}$) (DIN 18164)	75-80	80-85	80-85
Thermal expansion coefficient (1/4)	$5-7 \cdot 10^{-5}$	$5-7 \cdot 10^{-5}$	$5-7 \cdot 10^{-5}$
Specific heat capacity (J/kgK) (DIN 4108)	1500	1500	1500
Water absorption capacity at 7 days - totally immersed in water (% volume)	DIN 53428	3.0	2.0
	1 year	5.0	4.0
Water vapor diffusion ($\text{g/m}^2 \cdot \text{d}$) (DIN 53429)	40	35	20
Vapor diffusion resistance coefficient (μ) (DIN 4108)	20/250	30/250	40/250

EPS that is used for buildings is produced in board shape. Also it is being sold in order to use for decorative purposes. Unit weight in production is varying between $10-30 \text{ kg/m}^3$ and production densities are 10-12, 12-14, 14-16, 16-18, 18-20, 20-22, 22-24, 24-26, 26-28, 28-30 kg/m^3 in unit weights. Production dimensions of EPS are $400 \times 100 \times 50 \text{ cm}$ and by using hot wire technique (min. 1 cm) it can be produced in any thickness wanted.

Today in the world, raw material of EPS is being produced 2.2 million tone/year and the heat insulation materials and quantities that are consumed in Turkey and Europe is given in Fig. 7.

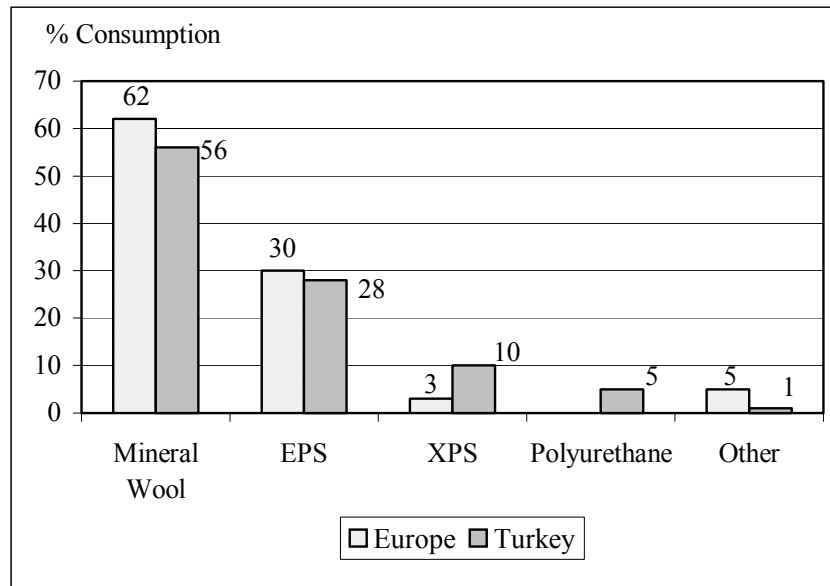


Fig. 7. Position of EPS in Applications of Heat Insulation Products [8].

3. DETERMINATION OF THERMAL CONDUCTIVITY COEFFICIENT

Kinds of construction & heat insulation materials are being improved with continuous development in technology. In thermal measurements, using thermal conductivity coefficient given in literature for similar materials may give wrong results. Because of this, all the physical properties of new materials like unit weight, viscosity, specific heat, thermal conductivity coefficients have to be determined [11].

The most important and most used test methods for solid matters are; Board with Protective Heater Method, Spherical Envelope, Cylindrical and Temporary Regime & Plate Method. In this study, in order to determine thermal properties of polystyrene boards “The Plate Method” that is determination of thermal conductivity coefficient with conduction, is used. The most important advantages of this method are; easy to perform, specimens used are in cube shape and provides total parallelization with horizontal in measurements where as the most important disadvantage is the thermal conductivities of specimens cannot be determined in moist state and conditioning is needed. Thermal conductivities & thermal transitions can be determined in straight plate state homogenous or near homogenous porous, fibered, grainy, one or more laminated specimens. In Plate Method, thermal conductivity coefficient is increasing with increase in slope angle with horizontal.

Using Plate Method to determine thermal conductivity coefficient will be appropriate because EPS forms from very little cells uniting from grains and it is used at construction in horizontal and/or vertical positions. It is not useful to use this method for materials; thermal conductivity is more than 2 kcal/mh°C (2.3 W/mK). Five types of unit weights (10, 15, 20, 25 and 30 kg/m³) are selected from products of EPS whose thermal conductivity coefficients are determined.

3.1. Experimental Apparatus & Applications

In order to determine thermal conduction coefficient, apparatus that determines thermal conductivity by Feutron type plate method is used (See Fig. 8) and this device can measure one specimen along each test period. Heater plate dimensions are 250x250 mm and it can measure up to 70 mm thickness. Cooler plate water and hot plate electricity are provided from connections that are connected with water and electricity networks. Equipment takes form from four main sections. These are; fixed bottom plate, moveable top plate and protective sheet and measurement apparatuses. Measurement apparatuses take form from three main sections, these are; thermometers, electric counter and micrometers that measures (0.001 mm) thickness.

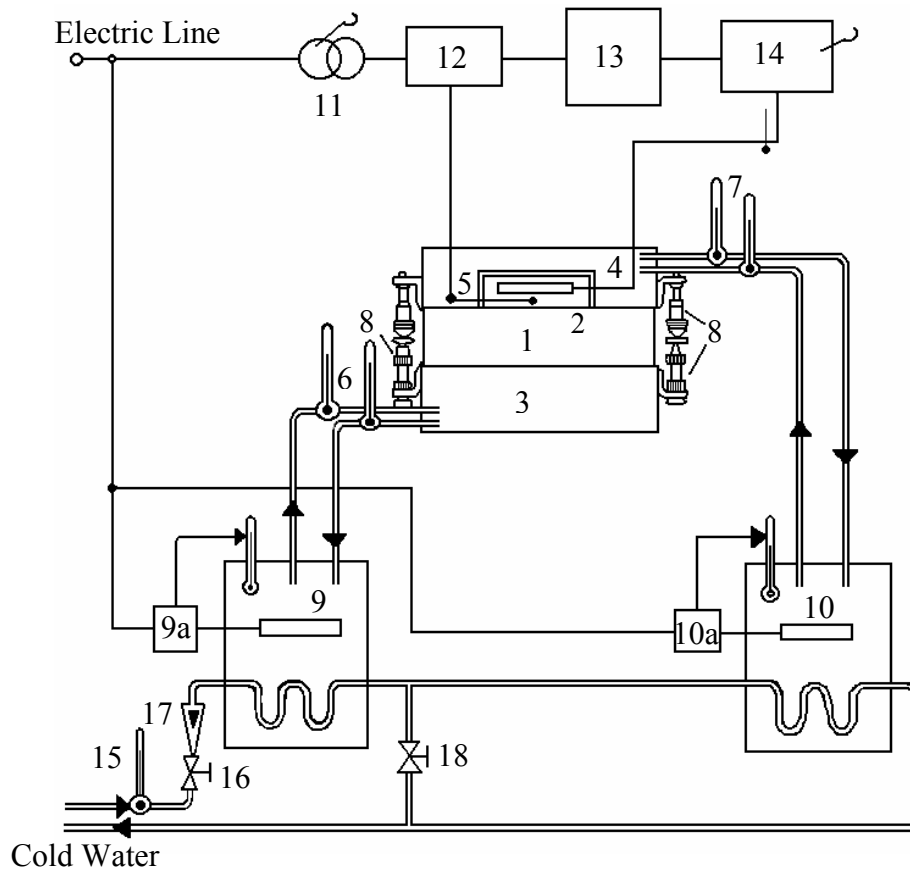


Fig. 8. Scheme of equipment that measures thermal conductivity by plate method [12].

- | | |
|---|---------------------------------|
| 1- Specimen | 10- Protective plate thermostat |
| 2- Hot plate | 10a- Heat regulator for 10 |
| 3- Cool plate | 11- Variable transformer |
| 4- Protective hot plate | 12- Two point adjuster |
| 5- Thermocouple | 13- Electric counter |
| 6- Thermometers of cool plate | 14- 12 digit voltmeter |
| 7- Thermometers of protective hot plate | 15- Cool water thermometer |
| 8- Thickness measuring micrometers | 16- Cool water valve |
| 9- Cool plate thermostat | 17- Flow meter |
| 9a- Heat regulator for 9 | 18- Short circulation valve. |

Heater plate is heated by electricity and warmness degree is adjustable. Cooler plate is cooled with Network water and coolness degree is adjusted with help of a vane by quantity of water flowing. Heat of network water is measured by a thermometer. Also by help of thermometers on warmer and cooler plates, heat of these plates is controlled.

Before starting the experiment, specimens are dried (24 hours at 105 °C) to changeless weight under normal atmospheric pressure (1×10^5 Pa). Practically, Expanded Polystyrene (mainly plastic) specimens lose their physical properties at 105 °C, therefore 24 hours drying procedure at 24 °C is performed. Humidity quantities by volume (n_v) and by weight (n_g) of specimens are calculated.

After preparing specimens, in order to measure, first of all working power quantity has to be determined. Power level is tied to specimen thickness and to approximate thermal conductivity coefficient. By using the diagram given in Fig. 9, approximate thermal conductivity coefficient value taken from DIN 4108 and the amount of thickness measured are put on the graph. From these values, the power level is read from the given diagram. Then, Ki coefficient is obtained from Table 2 according to found power level.

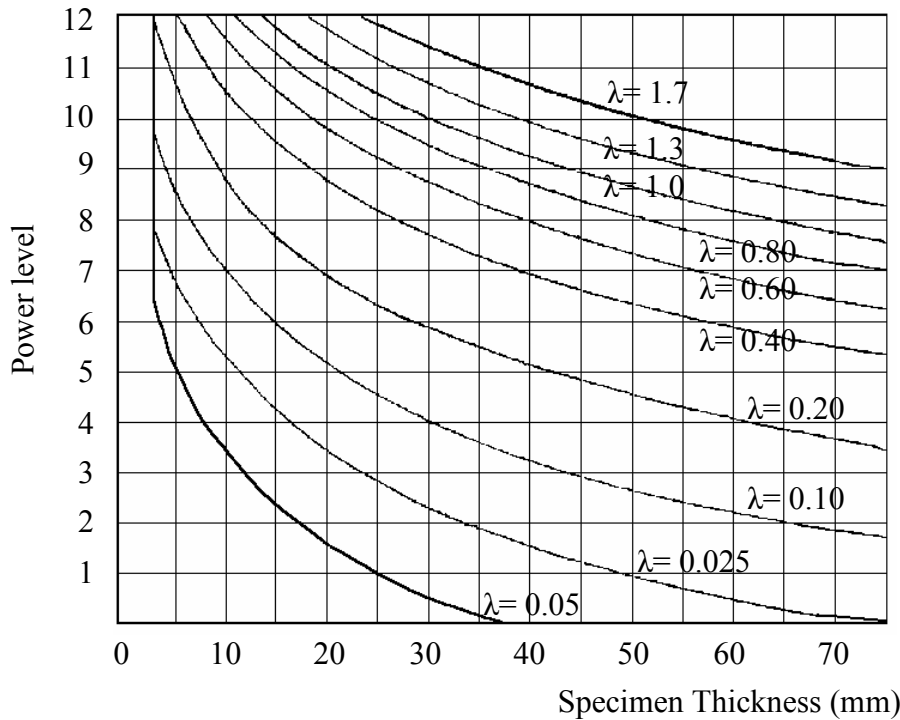


Fig. 9. The diagram to determine power level when fixed heat difference is 10 °C [12].

Table 2. Power level and Ki coefficients [12].

Power Source	Ki*	Power Source	Ki*
1	96.5	7	1031
2	139.6	8	1533
3	210.0	9	2232
4	307.2	10	3243
5	466.3	11	4691
6	694.2	12	6686

* Ki Power level coefficient contains measured area quantity, C counter coefficient and coefficients that translates wh to kcal.

After performing required adjustments, specimen is placed on the bottom fixed plate by being totally parallel to horizontal and, thicknesses at four corners of the specimen are measured by thickness measuring micrometers. Along the process of the experiment, the electric current passing from the electric counter and quantities at the thermometers of protective heater sheets are measured every half an hour totally 9 times. After completing the experiment, the thicknesses at the four corners of the specimen are measured again by the help of thickness measuring micrometers and average of these values is calculated. By determining electric quantity (wh/h) passing in unit time, current (q) is calculated by the help of equation 1 and by using power level coefficient (Ki). Heat difference (Δt) between two surfaces is calculated by averaging thermometer values of hot & cool plates. By equation 2, pre thermal conductivity coefficient ($\lambda_{10,\delta}$) of dry specimen is calculated using found values and correction coefficient (ω) that belongs to equipment. Because of the fact that material will be used in normal weather conditions, under normal atmospheric pressure, thermal conductivity value ($\lambda_{10,k}$) in dry condition is calculated by equation 3 on 10 °C average heat by adding an amount equals to moisture by weight quantity it contains in it. By adding 10% of thermal conductivity coefficient calculation value to itself, the value that will be used to calculate heat (Z) in order to use this material in buildings by equation 4 [14].

$$q = wh/h.Ki \quad (1)$$

$$\lambda_{10,\delta} = \frac{q.d}{\Delta t - q.\omega} \text{ kcal / mh}^\circ\text{C} \quad (2)$$

$$\lambda_{10,k} = \lambda_{10,\delta} / [1 + (n_g/100)] \quad (3)$$

$$\lambda_h = \lambda_{10,k} + Z \quad (4)$$

4. TEST RESULTS AND DISCUSSION

At the end of studies and calculations performed for every unit weight, it is reached to the values given in Table 3. $\lambda_{10,\delta}$ values given in Table 3 are arithmetical average of specimens.

Change in thermal conductivity calculation value (λ_h) found by experiments is given at Fig. 10. It is found that, unit weight and thermal conductivity coefficient change reversibly. Change curve's shape is polynomial and Regression coefficient is 1. ($y = 2 \times 10^{-05} x^2 - 0.0013 x + 0.057$, $R^2 = 1$).

As can be seen in Fig. 6, only one value (for $\geq 15 \text{ kg/m}^3$, 0.040 W/mK) is given for expanded polystyrene hard foam boards in TS 825 and DIN 4108; for other densities, it is not defined how to calculate or a value is not given. In PrEN 12524, for products that are not performed any tests 0.060 W/mK is given and, unit weight and thermal conductivity coefficient changes polynomially parallel to number of tests, for reliabilities of % 50 ($R^2 = 0.9788$) and % 90 ($R^2 = 0.9702$) two different thermal conductivity calculation values are given. According to PrEN 12524, these two values at 23 °C are the same for % 50 and % 80 relative humidity.

Table 3. Calculation values of conductivity coefficient for EPS specimens

Density Group (kg/m ³)	Specimen Number	Dry weight of specimens		Surface density a . d (kg/m ²)	$\sum \Delta E$ total electric consumption (kWh)	$\sum \Delta Z$ total time (hour)	Δt heat difference	Current $\frac{\sum \Delta E}{\sum Z} . Ki$	First and last thicknesses average- d (m)	$\lambda_{10.0}$	$\lambda_{10.k}$	$\lambda_{10.k} + Z$	Conductivity coefficient calculation value (λ_h)	
		Kg	(a) Kg /m ³							Kcal/mh°C			Kcal/mh°C	W/mK
10	1	0.02334	10.08	0.405	0.366	4	9.850	8.82975	0.04020	0.0361	0.0360	0.03960	0.039	0.046
	2	0.02337	10.02	0.406	0.366	4	9.900	8.82975	0.04048	0.0361	0.0360	0.03960	0.039	0.046
	3	0.02287	9.96	0.397	0.375	4	9.990	9.02275	0.03986	0.0361	0.0360	0.03960	0.039	0.046
15	1	0.03445	15.05	0.598	0.342	4	9.885	8.25075	0.03974	0.0332	0.0331	0.03641	0.036	0.042
	2	0.03423	14.88	0.594	0.339	4	9.865	8.17838	0.03994	0.0332	0.0331	0.03641	0.036	0.042
	3	0.03467	15.09	0.602	0.343	4	9.960	8.27488	0.03989	0.0332	0.0331	0.03641	0.036	0.042
20	1	0.04588	20.04	0.797	0.314	4	9.805	7.57525	0.03975	0.0307	0.0306	0.03366	0.034	0.039
	2	0.04637	20.10	0.805	0.317	4	9.975	7.647625	0.04005	0.0307	0.0306	0.03366	0.034	0.039
	3	0.04523	19.95	0.785	0.321	4	9.940	7.744125	0.03936	0.0307	0.0306	0.03366	0.034	0.039
25	1	0.05752	25.12	0.999	0.303	4	9.985	7.309875	0.03975	0.0291	0.0290	0.03190	0.032	0.037
	2	0.05805	25.05	1.008	0.297	4	9.915	7.165125	0.04023	0.0291	0.0290	0.03190	0.032	0.037
	3	0.05828	24.97	1.012	0.297	4	9.990	7.165125	0.04052	0.0291	0.0290	0.03190	0.032	0.037
30	1	0.06907	29.92	1.199	0.282	4	9.690	6.803250	0.04008	0.0282	0.0281	0.03091	0.030	0.036
	2	0.06962	30.03	1.209	0.296	4	10.200	7.141000	0.04025	0.0282	0.0281	0.03091	0.030	0.036
	3	0.06927	29.94	1.212	0.294	4	10.120	7.092750	0.04017	0.0282	0.0281	0.03091	0.030	0.036

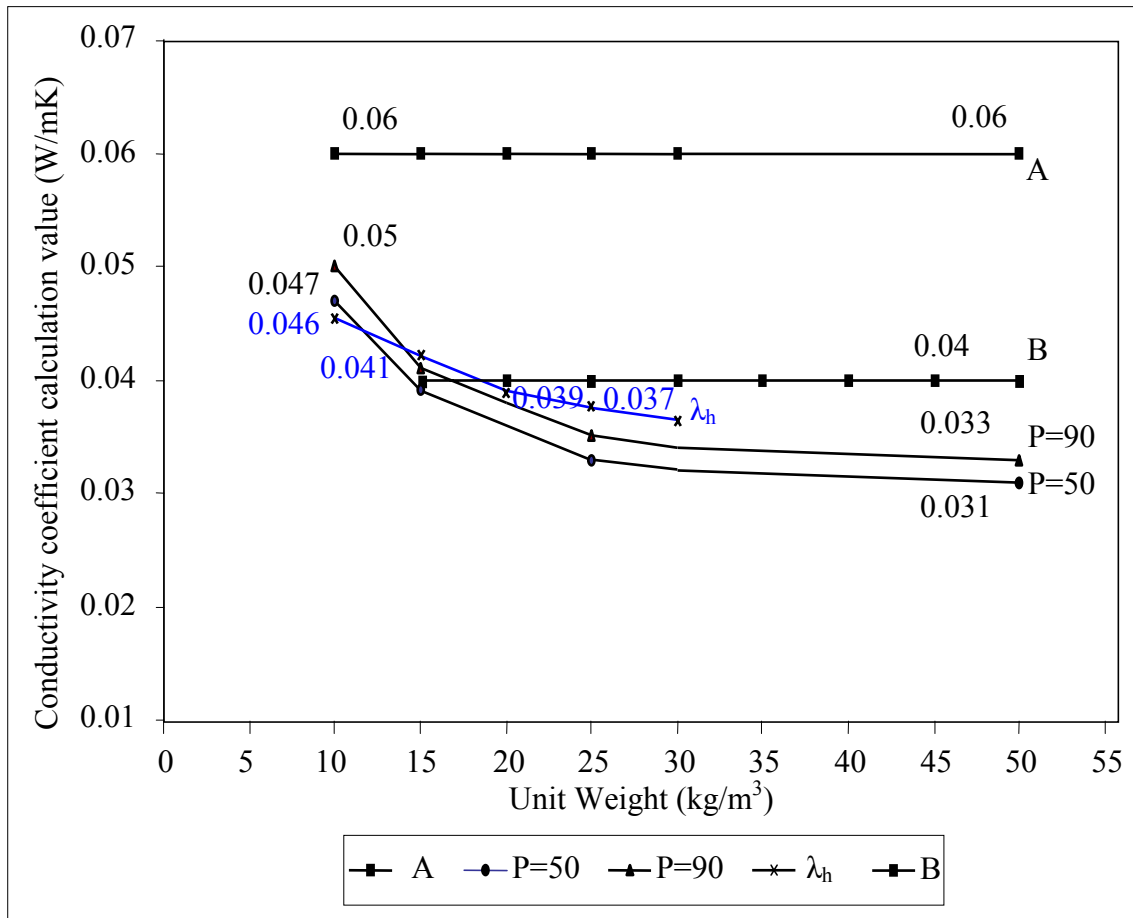


Fig. 10. Thermal conductivity coefficient calculation values of EPS, found by tests and on standards.

A: is the thermal conductivity coefficient calculation value for products (EPS) any tests performed given in PrEN 12524 [15].

B: Thermal conductivity coefficient calculation value used for expanded polystyrene hard foam boards densities bigger than 15 kg/m³ according to TS 825 and DIN 4108 [13, 16].

P=50 - P=90 : Thermal conductivity coefficient calculation values that will be used for products (EPS) at 50% and 90% meaningfulness levels given in PrEN 12524 [15].

λ_h : Thermal conductivity coefficient calculation value found at tests.

From the results of the experiment, although the thermal conductivity coefficient calculation values of EPS with unit weights 10-20-25-30 kg/m³ were found less than the limit values given in TS 825, DIN 4108 and PrEN 12524, except the value given in PrEN 12524 for specimens any tests performed, it is proved that EPS with unit weight 15 kg/m³ is more than other values.

4. RESULTS

When determining thermal conductivity values of construction materials that will be used for building heat insulation, knowing physical properties of materials (structure, torsion strength, etc) and using appropriate techniques will make possible to reach more correct results. Determining thermal conductivity coefficients after production phase of construction materials will force producer to produce high quality materials and also will satisfy the appropriate economical conditions by reducing the thicknesses of insulation materials used at buildings

It is determined at the tests of EPS products that, thermal conductivity coefficient changes reversely with density. Thus, we may conclude that, decrease of thermal conductivity coefficient is provided by increase in number of EPS grains in unit volume results in less void volume between grains and also result increase in number of pores in the EPS grains. However, this decrease in thermal conductivity coefficient is valid till to an optimum value because of the fact that, decrease in the amount of total voids in EPS will result an increase in compacity thus, thermal conductivity coefficient value may increase.

Only one value is given in literature and standards for thermal conductivity coefficient of EPS and, any method is suggested for change in this value according to unit weight. It will be more appropriate to change thermal conductivity coefficient value like the way given in PrEn 12524 according to number of specimens in order to develop new and better materials using the results found at experiments by using a value calculated by multiplying thermal conductivity coefficient value with a security coefficient.

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